State & Private Forestry
FOREST HEALTH PROTECTION
Northern California Shared Service Area

Date: July 26,2023

Topic: Drought, insect, and diseases affecting Douglas-fir in Northern California Shared Service Area, especially Shasta-Trinity National Forest (FHP Report NC23-002).

Key Points:

- ***The cool, wet, and snowy year brought major drought relief after three consecutive dry years. Groundwater infiltration and reduction of tree mortality can require more than one good year of precipitation.***
- ***Douglas-fir does not generally tolerate extreme drought conditions well. Current Douglas-fir mortality is primarily caused by flatheaded fir borer as a response to drought, but other agents may also be involved.***
- ***Douglas-fir mortality patterns in northern California may have implications for management. Species diversity in mixed conifer systems and restoration of oak-dominated systems may be key to considering next steps following tree mortality.***

The 2022–2023 water year started off with a few modest storms bringing snow accumulations to the mountains in early November. By the start of December, snow water equivalent (SWE) across much of the region was above normal. Starting in early December, several storm cycles brought moisture-laden atmospheric rivers to the West Coast. The strongest series of storms occurred steadily from December 27 through January 17. By the end of January, SNOTEL sites across much of the Sierra Nevada and Great Basin were at >150% of normal SWE. Unlike the 2021–2022 water year, in which snowfall was abundant early in winter but scarce after early January, the storm train continued with another series of strong storms from late February through mid-March. By April 1, snowpack was well above normal across California, with few areas of snow drought. (CA Dept. of Water Resources https://water.ca.gov/Water-Basics/Drought)

For California, the cool, wet, and snowy year brought major drought relief after three consecutive dry years. Observed water year runoff was above normal through early June, and the forecasts indicate above-normal flows persisting throughout summer. Major reservoirs have already filled or are expected to fill by the end of summer. Wet years like this one are not unprecedented in the context of the current multidecadal drought. Long-term drought recovery is complex, and it is important to note that groundwater infiltration and recharge of aquifers, which is impacted by the characteristics of snowmelt, can take longer to respond and require more than one good year of precipitation. California's climate can swing from wet years to dry years and back again. Climate change is increasing this variability.

Putting this information into context of forest health and the continued tree mortality trends in Northern California can be difficult. There are many areas in Shasta, Trinity, and Siskiyou Counties where Douglas-fir continues to die from attacks by the flatheaded fir borer (*Phaenops drummondi*) and mortality of ponderosa pine increased over the last year due to western pine beetle (*Dendroctonus brevicomis*). Other tree species experiencing increased mortality over the past year include true firs and incense cedar, each for a variety of reasons but thought to be driven by hot and droughty conditions. Tree

mortality is extremely high in Trinity and Shasta Counties and may have an impact on summer recreation.

There is a lot of information regarding western pine beetle-caused mortality of ponderosa pine especially following the 2015 Southern Sierra outbreak. Much less is known about the more recent mortality events involving Douglas-fir in northern California. The Shasta-Trinity, as well as other Northern California mixed conifer forests has seen many acres of Douglas-fir mortality over the past three years. The 2022 Aerial Detection Survey Results: California reported that nearly all Douglas-fir mortality was caused by flatheaded fir borer with an estimated 3 million dead trees across 190,000 acres, compared to ~170,000 dead trees across 18,000 acres in 2021 (Moore et.al. 2023). The report also goes into detail regarding the increase in true fir mortality attributed to fir engraver beetle (*Scolytus ventralis*). Mortality was most severe and widespread throughout the central Sierra Nevada Range, but Shasta red fir mortality has increased across the Shasta-Trinity especially surrounding Mount Shasta. While true fir mortality is also strongly associated with drought conditions, this report will focus primarily on the Douglas-fir mortality.

Douglas-fir does not generally tolerate extreme drought conditions well. As a part of the pine and mixed conifer forest types, Douglas-fir mortality is primarily caused by flatheaded fir borer as a response to drought. Flatheaded fir borer is a Buprestid wood boring beetle that behaves like a bark beetle (e.g., Western pine beetle in ponderosa pine) by feeding entirely underneath the bark instead of excavating galleries in the wood (Furniss and Carolin 1977; Schaupp and Strawn 2016). The life cycle of the flatheaded fir borer normally lasts for one year but can be longer (2-4 years), depending on the quality of host as a food source. Adults emerge in the spring (March - April) and feed on conifer needles before flying to a suitable host tree. Eggs are laid in bark crevices and upon hatching, larvae immediately bore into the inner bark. Larvae feed mostly on cambium and some phloem without entering the sapwood. Late in the summer or early fall (August - September), larvae move to the outer bark where they construct pupal cells and overwinter. Adult beetles emerge the following spring.

Flatheaded fir borer commonly kills healthy looking Douglas-fir growing at lower elevations on warm, dry sites around interior valleys or in locations where available moisture may be limiting (Goheen and Wilhite 2021, Buhl et al 2017). It is particularly aggressive during and after periods of drought. Patterns of mortality are often clumped on the landscape and concentrated along outer edges of stands, along ridges or drainages. Periods of extended drought also provide the environmental conditions for so called "secondary beetles" such as the Douglas-fir engraver beetle (*Scolytus unispinosus*) and Douglas-fir pole beetle (*Pseudohylesinus nebulosus*) to successfully attack and weaken mature Douglas-fir making them more susceptible to the flatheaded fir borer. Douglas-fir pole and engraver beetles typically attack small-diameter Douglas-fir trees and the tops of larger trees. Douglas-fir pole beetles and engraver beetles have one to two generations per year. Beetles usually emerge and attack in the spring.

The most important pathogens of Douglas-fir in these mixed conifer forests include root disease fungi (*Armillaria* spp. and *Leptographium wageneri* var. *pseudotsugae*), butt- and heart-rot fungi (*Phaeolus schweinitzii* and *Porodaedalea pini*), and dwarf mistletoe (*Arceuthobium douglasii*). All are native to northwestern California and have co-evolved with their hosts for millions of years. These pathogens interact with insects to drive the background mortality rate of Douglas-fir. In a study in old-growth stands on the Six Rivers National Forest in the Coast Range of northern California, Douglas-fir mortality (percentage of trees that were found to be dead during sample period) was 13%, and 97% percent of that morality was associated with pathogens and/or insects (Hawkins and Henkel 2011). For most of these pathogens there is little or no known resistance since their hosts may persist and reproduce for many decades, and often centuries before being killed, often by insects such as the flatheaded fir borer. Co-occurrence of pathogens and insects are common and account for most of the biotic-driven mortality in

Douglas-fir forests. Attack by weak pathogens and insects may be facilitated by the presence of more aggressive species but aggressive pathogens and/or insects may also co-occur on individual trees.

Armillaria species are important root-disease pathogens of forest trees and woody crop plants in western North America. Important *Armillaria* species present in Douglas-fir forests in the Pacific northwest include *Armillaria ostoyae*, *A. gallica*, *A. mellea*, and. *Armillaria ostoyae* is the most damaging *Armillaria* species in western North American forests and has been reported in Washington and Oregon and elsewhere on Douglas-fir and other conifer species (Shaw and Kile 1991). Although it has not been reported in California, it is likely that *A. ostoyae* is present in the Klamath and Cascade Ranges of California given the contiguity of those ranges between southern Oregon and northern California (Baumgartner and Rizzo 1991). *Armillaria ostoyae* can attack and decay the root system of healthy trees. Because of the ability to grow from an infected root system to an adjacent uninfected root system, *Armillaria*-induced mortality occurs in a circular, outwardly expanding pattern starting from a focal tree ("disease center"), with the most recent mortality at the edge of the disease center. All conifer and many hardwood and shrub associates of Douglas-fir are susceptible, but the degree of susceptibility may differ between species (Allen et al 1996). Moist soil conditions favor the growth of *Armillaria* species and the development of Armillaria Root Disease.

Black stain root disease of Douglas-fir, caused by the fungus *Leptographium wageneri* var. *pseudotsugae* (=*Grosmannia wageneri*), is a vascular wilt disease that results in the blockage of the water conducting cells of host trees making them highly water stressed. *Grosmannia wageneri* is an important root disease pathogen of Douglas-fir, primarily infesting young stands (15 – 30 years; Allen et al 1996). Local dispersal occurs via root grafts and connections from infected root systems to adjacent uninfected root systems, while long distance dispersal occurs via root-feeding insects that vector the fungus from infected to uninfected trees. High host density and moist sites favor disease development. Since this fungus is host specific, low tree species diversity also favors infestation and disease development. Increases incidence of black stain root disease have been associated with thinning and second growth Douglas-fir forests.

As landscapes become increasingly droughty with climate change, the impacts of insects and diseases on Douglas-fir and other tree species will likely increase (Agne et al. 2018; Halofsky et al. 2022). Therefore, it is thought that recent Douglas-fir mortality patterns in northern California and southern Oregon may have implications for management. Recent increases in Douglas-fir mortality raise concerns about the long-term resilience of this species, the loss of key ecosystem services, and the potential for increased fuel loading and uncharacteristic wildfire (Hessburg et al. 2019). At the same time, Douglas-fir mortality on some sites, such as former oak woodlands, presents opportunities for restoration.

Bennett et.al. (2023) used Mannion's "decline disease spiral" as a framework for hypothesizing the interaction of environmental variables that contribute to Douglas-fir mortality in the Klamath ecoregion. This framework describes a process whereby predisposing, inciting, and contributing factors lead to progressive loss of tree vigor and eventual death (Mannion 1991). Specifically, trees growing on marginal, water-stressed sites (predisposing factors) are more vulnerable to episodic drought stress (inciting factors) that impairs their physiological functioning, making them more susceptible to flatheaded fir borer and other biotic agents (contributing factors), resulting in tree decline and death. As entomologists and pathologists in Forest Health Protection have long said, it is hardly ever a single factor that kills a tree. Carbon starvation and hydraulic failure may occur as a precursor to these biotic agents or may be amplified by them (McDowell et al. 2008). Although most Douglas-fir mortality in the ecoregion has been attributed to the flat headed fir borer in the annual aerial survey, the actual causes of mortality, as well as site factors, may be more complex and need validation by systematic field investigation.

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